RESEARCH HIGHLIGHTS

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INVESTIGATION PROTOCOL FOR EVALUATION OF POST-TENSIONED BUILDINGS

Introduction

More than 100 million square metres (one billion square feet) of concrete structures in North America have been built using unbonded post-tensioned reinforcement. This reinforcement consists of high-strength steel strands that are coated with a layer of grease, inserted into plastic sheathing and anchored to the building. The complete assembly—including the strands, sheathing and anchor—is called a tendon. The strands are tensioned at one or both anchors using a hydraulic jack.

Unbonded post-tensioned buildings perform well provided the tendons are kept free from moisture. However, problems became apparent in the 1980s, with tendons corroding and breaking, due to moisture penetration, in many structures built prior to the late 1980s. High-strength steel strands are particularly susceptible to corrosion.

Strand corrosion in post-tensioned structures and the time to strand breakage vary widely between buildings and even within an individual building. Some structures have experienced widespread strand breakage within seven years of construction, while in others breakage is beginning to occur after 25 years.

An investigation program involving selective exposure and testing of strands is necessary to 1) assess safety, 2) predict the likelihood of future strand breakage and 3) decide if monitoring or repair is required. Inspection can be costly and disruptive, and repair even more so. Since the 1980s, investigation protocols for post-tensioned systems have evolved considerably.

Investigation Protocol for Evaluation of Post-Tensioned Buildings is a research document that can assist engineers in planning and conducting an appropriate evaluation program. It can also serve as a guide for owners, property managers and others in understanding the process. The objectives of the document are to:

- identify factors contributing to the wide range of performance in unbonded post-tensioned systems
- note business influences and risk tolerance factors that impact on defining the scope of investigation
- outline current investigation techniques
- suggest appropriate investigation sampling sizes for different building types
- stipulate reporting requirements
- provide general information on maintenance options.

Investigation Protocol does not specify minimum levels of testing or maintenance standards, but rather provides insight and suggestions regarding the evaluation process. It deals only with buildings constructed with unbonded, single-strand, post-tensioned tendons. Different procedures are involved in assessing grouted (bonded), single- and multi-strand post-tensioning systems and pretensioned (precast) building components.

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Preparing for an investigation

The major factors influencing the potential for strand corrosion and breakage are 1) the amount and extent of moisture access, 2) contaminants within the sheathing and 3) susceptibility of the strands to develop stress corrosion cracking.

The scope of an investigation can be influenced by a number of factors. One, for example, is whether the client has short-term or longer term interests in the property. If long term, an assessment of conditions throughout the building, rather than selective testing in representative areas, may be best. This reduces the possibility of missing an area of greater deterioration. Conversely, if a client has only a short-term interest, or wants to minimize short-term expenses, a limited investigation may be suitable.

Similarly, an interest in redeveloping, as opposed to repairs or maintenance, will influence the scope of testing. The interests of financial and insurance institutions, or government agencies, can affect the extent of investigation. A general review of the structural design is an important first step that needs to be undertaken before the scope of testing can be confirmed. This should reveal the overall robustness of the design, critical areas, and specific items and problems to look for in the field.

This initial step involves reviewing all available documentation. While engineering drawings may not represent the actual post-tensioning systems used, as changes may have been made by suppliers according to their individual system designs, they will provide information on the general arrangement of the system. Construction photographs may provide information on anchorage details, the construction sequencing, hoarding and other measures that can affect moisture access during construction.

A preliminary visual inspection can help in confirming occupancy loads, obvious deviations from the original design and waterproofing details. Any areas with signs of visible distress will indicate the need for special investigation.

The *Investigation Protocol* provides guidance on these and other aspects of the initial review, including how to determine sample size and proportioning, and selection of recess locations for inspection.

Reasons for Investigating Post-Tensioned Systems

Investigation of post-tensioned systems may be prompted by one or more of the following requirements:

Pre-purchase due diligence
Pre-financing due diligence
Directives from municipal building officials
Response to visible distress
Routine condition inspection
Maintenance expenditure forecasting
Building operation cost audit
Capital reserve fund study
Remaining service life prediction
Litigation
Change in intended use of the structure

Undertaking an investigation

This phase begins with a more detailed field investigation. This work is necessary to confirm superimposed loads and as-built details, including the presence and condition of waterproofing in areas not readily visible. Field observations should be documented for future reference. Standard data collection forms should be used, as this will simplify data recording and reduce the likelihood of errors or omission of key information. Sample inspection forms are included in Appendix A of the guide. A contractor with demonstrated experience in unbonded post-tensioned construction can provide invaluable knowledge on tendon layout, anchor details and stressing procedures.

Investigations generally proceed as follows:

- *Strand inspection at recesses*
  Preliminary assessment program typically includes testing of short lengths (200mm) of strands exposed at inspection recesses chipped into the concrete structure at a number of representative locations. Visual inspection for moisture should be done as soon as the strands are exposed, as any moisture within the sheathing may rapidly drain or evaporate upon exposure. Grease samples should be tested for water and strand tension assessed using one or more of three tests: cut-wire, screwdriver penetration or a deflectometer. These tests are described in Appendix B of the guide.

- *Strand extraction and inspection*
  Removing and inspecting a small number of strands can yield additional information regarding the extent of moisture present in the system and the degree of strand corrosion. If testing in the previous step indicates strand tension deficiencies, a number of the suspect strands should be removed to determine the cause of tension deficiency.

- *Metallurgical analysis and testing of strands*
  Additional tests are often performed to identify the deterioration mechanism and help in predicting the time to failure of corroded strands. Such tests are briefly described in the guide.

- *Measurement of humidity within strand sheathing*
  An air test can be conducted on push-through or heat-sealed sheathing to indicate the potential for strand corrosion. (Tighter fitting and grease-filled extruded sheathing prevents air flow, which precludes this form of testing.) The test has the advantage of providing information regarding moisture along an entire strand length rather than just at inspection points.

- *Analysis of sheathing contaminants*
  Pure water can initiate corrosion of strands. In addition to pure water, a number of contaminants can exacerbate strand corrosion. These could be, for example, chlorides or fertilizer that have penetrated the sheathing in below grade parking decks or slabs under landscaped areas. The grease inside a sheathing may be contaminated with nitrates, valences of sulphur, fungi or microbiological activity that is producing hydrogen sulfide.

Expert judgment must be exercised in interpreting results obtained at inspection recesses, as they may not reflect overall conditions. Expertise and familiarity with the design of post-tensioned structures is required to correctly assess the impact of strand breakage on a building's structural capacity.

Knowing the tolerable tendon loss ratios and strand failure rates will assist in estimating the length of time until repairs are required. Other factors, though, must be taken into consideration as well. A building's test results and other specific information must be taken into account in predicting future performance, as strand breakage does not occur uniformly over time. Typical results suggest corrosion advances within a system to a threshold level, at which point the frequency of strand breakage increases.

Strand failure can occur quite suddenly, with a significant amount of energy being released. In a limited number of cases, eruptions have occurred. Given the potential for personal injury or property damage arising from this, it is recommended that steel plates or other restraint measures be used at locations adjacent to pedestrian areas and where concrete cover is reduced (at high and low points in the strand drape).

Reporting standards to date for post-tensioned investigations have been inconsistent. As a result, reports from different consultants can present conflicting opinions. They may fail to identify serious safety issues, or provide ambiguous or incorrect conclusions based on limited testing information. Inconsistent use of terminology within the industry makes it especially difficult for non-experts to understand the reports. The *Investigation Protocol* offers an outline of the information that should be covered in a typical evaluation report, from background information and summary of test results to repair and maintenance recommendations.

Where past or present problems exist, continued monitoring of strand tension is recommended. An acoustic monitoring system can identify ongoing strand breakage throughout a structure, thus reducing the uncertainty in predicting future strand breakage and the timing of repairs.

When tension deficit strands are identified, strand replacement may be done on a selective basis, or repairs could involve replacing all strands once the tolerable tendon loss ratio is reached. Sealers and membranes can be used to reduce moisture access into the structure. As an alternative to waterproofing, improvements can be made to the system such as sealing the anchors, drying the tendons or preventing moisture penetration by injecting additional grease or urethane into the sheathing. Improving drainage is useful if it reduces the likelihood of moisture penetrating the concrete and tendons. Plugged drains should be cleaned and repaired. Additional drains or sloped toppings will help eliminate any pooling of moisture. Roof slopes can be improved by adding tapered insulation, and berms and swales can be added to direct water away from anchorage zones to drains.

Conclusion

Post-tensioned structures are unlike ordinary reinforced concrete structures. Assessing their condition requires considerable expertise with post-tensioned systems. Damage is not usually evident externally, even if strand breakage is extensive, and conditions can vary widely even within an individual structure.

Assessment of strand metallurgy and corrosion mechanisms is a relatively new area of study, with little understanding of how specific factors relate to time to failure of strands. Considerable judgment must be exercised in conducting an investigation to evaluate the condition of a post-tensioned system.

The *Investigation Protocol* provides important information and suggestions for experts, while presenting a good overview of the process for owners, property managers and others interested in assessing unbonded post-tensioned structures.

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Research Report: *Investigation Protocol for Evaluation of Post-Tensioned Buildings*, 2002

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Housing Research at CMHC

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